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A TIME-OF-FLIGHT NEUTRON SPECTROMETER

by P. E. TRIER *), J. C. HAMMERTON **) and E. WOLFENDALE *). 539.185.7

The study of neutron absorption by different elements is of great importance in nuclear physics as it yields valuable evidence on the composition and binding forces of atomic nuclei, and on the suitability of materials for atomic piles. A widely used method of measuring neutron absorption as a function of neutron energy is the time-of-flight spectrometer. An instrument of this type constructed for A.E.R.E., Harwell and used in conjunction with the 15 MeV linear accelerator described earlier in this Review, is the subject of this article.

Introduction

Neutron reactions

Neutrons are among the most penetrating particles known to modern nuclear physics. A description of the effect of a sample of material upon a beam of neutrons has been given in a paper by Taylor and Havens [1]) but a brief summary will be useful here.

A beam of neutrons passing through a sample of material suffers an attenuation due to interaction between some of the neutrons and the nuclei of the material. This interaction may take several forms, e.g. absorption and elastic or inelastic scattering of neutrons. Many elements exhibit regions of "resonance absorption" as shown by a marked increase of the attenuation of the beam at definite values of neutron energy.

For a thin sample the decrease in intensity of the beam is given by the formula:

$$I = I_0 \, e^{-\sigma_t n l},$$

where I_0 is the initial intensity of the neutron beam, I is the intensity after passing through the sample, n is the number of nuclei per cm^3 of sample, l is the thickness of the sample, σ_t is the total cross-section in cm^2, which (by this formula) is defined as the effective area presented by the nuclei to the neutron beam.

The total cross-section σ_t depends upon the velocity of the neutrons, and "resonance absorption" is mathematically expressed as a maximum occurring in σ_t at definite values of neutron energy. A careful study of these energy levels for different elements will yield valuable experimental evidence about the composition and binding forces of atomic nuclei.

Some information has been obtained about neutron absorption by studying the radioactivity caused by direct activation of samples of elements by neutrons. These experiments are neither simple to perform nor capable of any great accuracy. Quantitative evaluation of resonance cross-section necessitates the use of some form of velocity spectrometer.

Time-of-flight spectrometers

The most flexible and most widely used method of measuring neutron reaction cross sections of elements in the energy region 1 eV to 20 keV makes use of a time-of-flight spectrometer. A neutron source is periodically made to emit neutrons for a short time. The neutrons travel over a distance L and the neutron pulse, which has a continuous energy spectrum, becomes spread out along its direction of travel as the slower neutrons lag behind the faster ones. After a time T from the release of

*) Mullard Research Laboratories Salfords, England.
**) Atomic Energy of Canada Ltd, formerly at the Mullard Research Laboratories.

1) T. J. Taylor and W. W. Havens Jr., Nucleonics 5, 4. 1949.

the pulse, a particle detector in the path of the beam is rendered sensitive for a short interval ΔT and the number of neutrons arriving in this interval is recorded by electronic scaling circuits and mechanical counters. The recorded count gives a proportional indication of the number of neutrons with velocity L/T. By continuing the counting over a large number of neutron pulses and by varying T over a range, a graph of the energy distribution can be obtained.

Most of the early adaptations of this method were limited to inspection of an interval ΔT at one particular delay T per experiment, but modern time-of-flight spectrometers obtain more than one reading at a time by arranging to switch the output of the detector over a range of values for T by using a multiple bank of electronic "gating" units.

The actual measurement of total cross section is effected in the following way. The energy distribution of the neutrons in the incident beam is ascertained; a sample of the element under investigation is then interposed between source and detector. The total cross section of the element in any given energy interval is then determined from the transmission factor I/I_0 obtained from the modification of the energy spectrum of the detected neutrons.

The energy E of the neutrons is determined with an accuracy ΔE. The ratio $\Delta E/E$ is called the resolution of the spectrometer. This resolution is dependent upon the accuracy of determination of both L and T. The length L of the flight path is subject to uncertainty because of the finite depth of both source and detector. The time of flight T is subject to some indeterminacy since the neutron source is pulsed for a time which may not be small compared with T when dealing with high energy neutrons; furthermore the inspection period ΔT is also finite.

The resolution can be improved by reducing the depth of the detection chamber, reducing the duration of the neutron pulse or the inspection period ΔT, or by increasing the path length L. All these improvements result in a reduction of the counting rate, and since a reasonable counting rate is required, the principal factor limiting the resolution of a spectrometer is the available neutron flux at the source.

The statistical accuracy of the spectrometer is not affected by the average detector counting rate, provided that this is large compared with any random background counting rate, but it depends on the total number of counts and varies as the reciprocal of the square root of this number. Hence the need for a reasonable counting rate if experiments are not to be unduly protracted.

Two examples of early time-of-flight spectrometers, using a single inspection period per experiment are those of Luis Alvarez [2]) and Baker and Bacher [3]). In both cases the resolution was limited by the duration of the neutron pulse, that of Baker and Bacher being the best with a neutron pulse of from 50 to 500 μsec long.

The first time-of-flight spectrometer employing more than one inspection period per experiment was that of Haworth, Manley and Luebke [4]). This spectrometer aimed at a higher order of precision but the strength of the source limited the study to neutrons with energies between 0.004 and 1 eV.

This was followed by a spectrometer built at Columbia University by Rainwater and Havens [5]), using an 8 MeV cyclotron, and by a spectrometer built by the Mullard Research Laboratories and the Atomic Energy Establishment, Harwell [6])[7])[8]). It is interesting to compare the salient points of these spectrometers.

The Columbia University spectrometer had a minimum neutron pulse length of 5μsec, and a minimum inspection period of 5 μsec. The number of intervals capable of being investigated simultaneously was 16 and the neutron path length was 6.2 metres. A moderating paraffin block had to be used to slow down the higher energy neutrons to useful levels; this introduced a further uncertainty in the time at which a neutron left the source. The resolution of the Columbia University Spectrometer has since been improved by reducing the neutron pulse length to 4 μsec and the inspection period to 2 μsec. This improvement and some typical results are described in a paper by Havens and Rainwater [9]).

The Harwell time of flight spectrometer was capable of giving improved resolution at low and high energies owing to the use of a travelling wave linear accelerator with an electron pulse of 120 mA at an energy of 3.2 MeV. This ensures a sufficiently high

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[2]) Luis W. Alvarez, Phys. Rev. **54**, 609, 1938.
[3]) C. P. Baker and R. F. Bacher, Phys. Rev. **59**, 332, 1941.
[4]) J. H. Manley, L. J. Haworth and E. A. Luebke, Rev. Sci. Instr. **12**, 587, 1941; Phys. Rev. **69**, 405, 1946.
[5]) J. Rainwater and W. W. Havens Jr., Phys. Rev. **70**, 136, 1946; J. Rainwater, W. W. Havens, C. S. Wu and J. R. Dunning, Phys. Rev. **71**, 65, 1947.
[6]) A. W. Merrison and E. R. Wiblin, Nature, **167**, 346, 1951.
[7]) A. W. Merrison and E. R. Wiblin. Proc. Roy. Soc. **A 215**, 278, 1952.
[8]) F. S. Goulding, J. C. Hammerton, M. G. Kelliher, A. W. Merrison and E. R. Wiblin, Proc. Inst. El. Engrs. 1954 II, Paper M 1528 (appearing shortly).
[9]) W. W. Havens Jr. and L. J. Rainwater, Phys. Rev. **83**, 1123, 1951.

flux of low energy neutrons (due to the moderating action of the source itself) to make the use of a paraffin moderator unnecessary. The increased flux enables the path length to be increased to 10 metres; and this, combined with an overall indeterminacy in the time of flight of only 6 μsec gives the improved resolution. The minimum neutron pulse and the minimum inspection period were both 2 μsec. The number of intervals capable of being investigated simultaneously was 32.

A further improvement in resolution is now being obtained at Harwell by the use of the 15 MeV linear accelerator [10]) together with a new timing system. The 15 MeV accelerator provides a further increase of flux, allowing the path length to be increased to 20 metres. The timing system, which was designed and built simultaneously with the accelerator by the Mullard Research Laboratories in conjunction with the Atomic Energy Research Establisement, is similar to that of the previous spectrometer except that the number of intervals simultaneously available for examination is increased to 100. This Harwell spectrometer will now be described in detail.

Fig. 1 gives a general view of the installation during construction. At the left the concrete shelter, containing the linear accelerator, is visible. In the centre one of the flight-paths can be seen with the detector at the extreme right. In the background is the electronic timing system which is the principal subject of this article.

Design of the Harwell Spectrometer

General description

A block diagram of the principal units of the spectrometer is shown in *fig. 2*. The heart of the installation is the 15 MeV linear accelerator previously described in these pages [10]). The 2 μsec electron pulse is used to irradiate a γ-ray and neutron source.

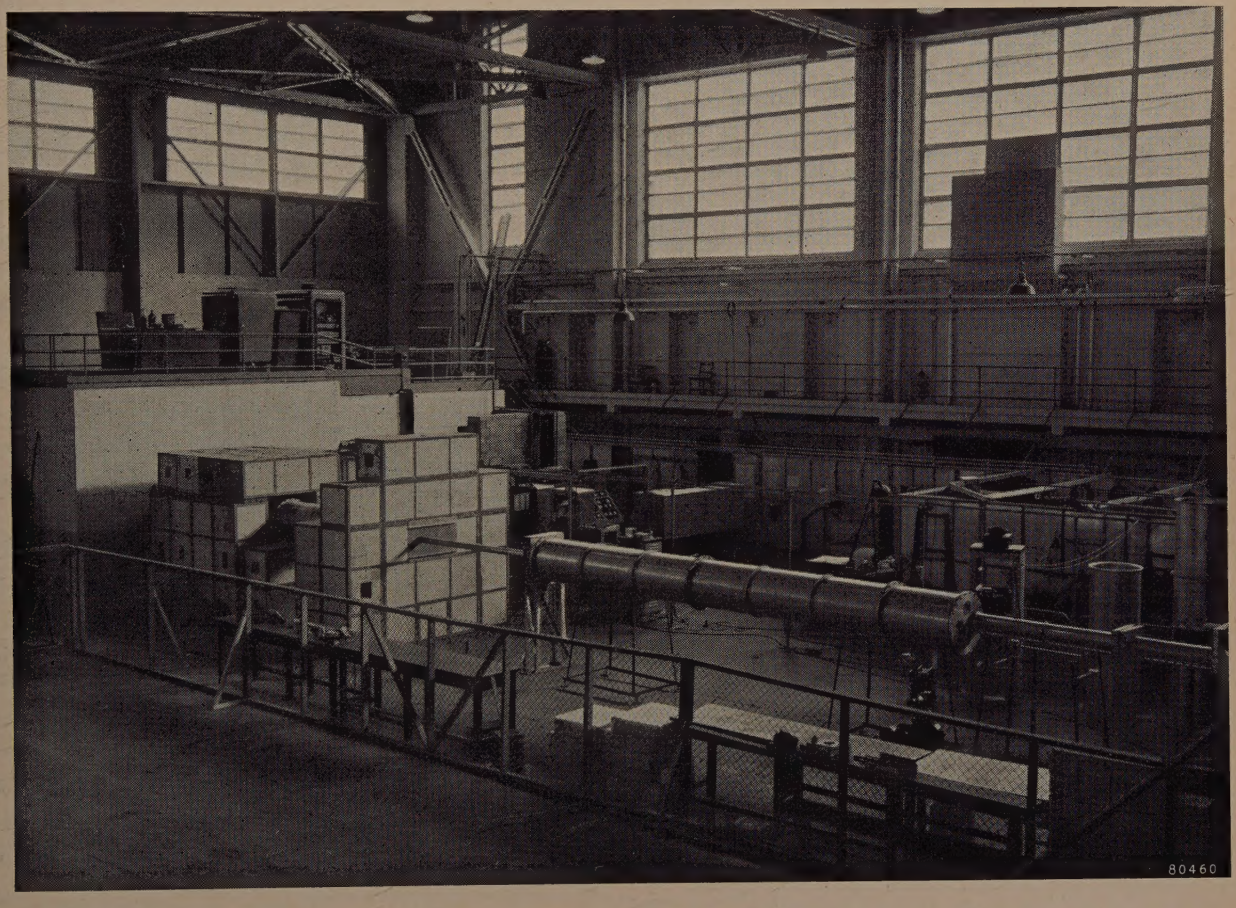


Fig. 1. General view of the neutron spectrometer at Harwell during construction.

The accelerator is housed in a heavy concrete shelter. Windows in the shelter near the neutron source provide exits for the neutrons into two roughly evacuated flight paths. Each flight path can be used separately for independent experiments.

[10]) C. F. Bareford and M. G. Kelliher, Philips Techn. Rev. **15**, 1-26, 1953 (No. 1).

A timing pulse, designated the modulator pulse, is generated in a *Master Timing Unit* and is used to initiate the high voltage pulse which is applied to the electron gun of the linear accelerator and to its magnetron. The neutron pulse of 2 μsec duration is emitted from the neutron source 1-3 μsec after the modulator pulse because of circuit delays.

The neutrons travel down each 20 metre flight path and are detected at the end of a path in a neutron detector. By now, the neutrons have become spaced out in time according to their energies. The electrical signal pulses from the detector therefore constitute a series whose distribution in time corresponds to the energy spectrum. This pulse series is fed via amplifiers to the common input rail of a bank of 100 gating units. The gating units are opened successively for equal short intervals ΔT, starting at a pre-set time T after the initiation of the

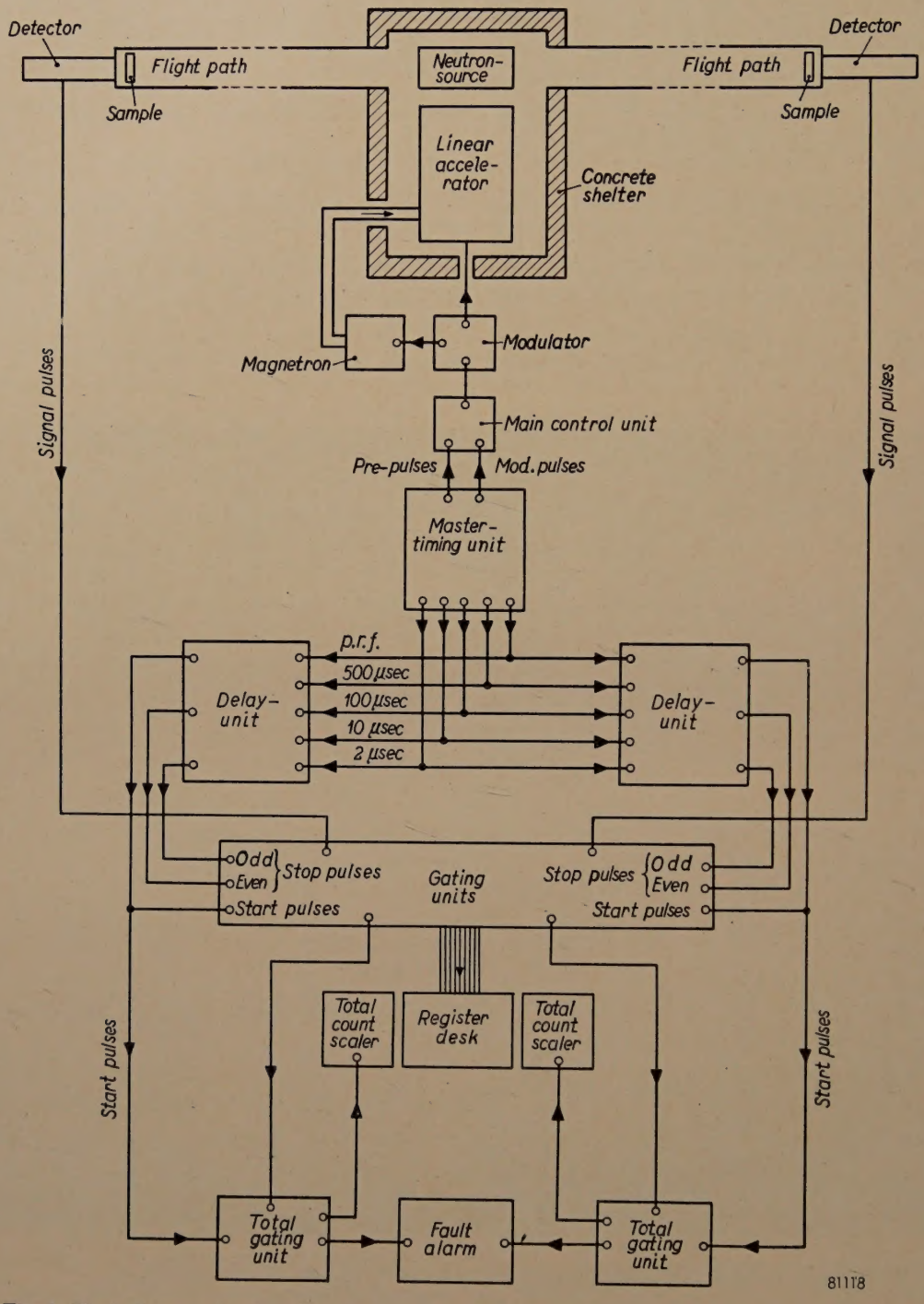


Fig. 2. Block diagram showing the principal units of the Harwell time-of-flight neutron spectrometer.

neutron pulse. Each gating unit output is fed separately via a pulse lengthener to a mechanical counter acting as a register. These counters are conveniently grouped together in a register desk. The gating units thus perform a sorting action, in such a way that the nth register will count only those pulses arriving at a time t from the initiation of the neutron pulse, such that

$$T + (n - 1)\,\Delta T < t < T + n\,\Delta T.$$

It should be pointed out here that for the release of one 2 μsec neutron pulse, each gating unit can register only one neutron arrival. The parameters of the system are however such that the probability of arrival of one neutron (let alone two or more neutrons) at any given gating unit interval as a result of a single neutron pulse release is exceedingly small. The statistical distribution is evaluated at the registers by a repetitive cycle at 200 or 400 neutron pulses per second. Even so, a run of some hours is usually required to build up an adequate count distribution.

The practical features of the Harwell instrument allow considerable flexibility of operation. The 100 gating units can be used either in a single sequence, or else in two independent banks of 50 units each for experiments on separate flight paths. A subdivision into 16 + 84 units is also possible.

The initial delay T before the initiation of the gating unit sequence is provided by a *Delay Unit* actuated by the master timing unit. The delay unit is capable of giving a delay from 0 to 2990 μsecs, adjustable in steps of 10 μsecs. The delay unit also incorporates circuits which determine the gating interval ΔT, which can be set at 2 μsecs or 10 μsecs per gate.

In order to allow the use of two independent gating unit chains, two identical delay units are provided, each having the features described above. If the whole chain of 100 gates is used as a single sequence, only one delay unit operates.

To provide a check on the correct operation of the gating units, a *Total Gating Unit* [11]) is provided for each chain, which gates the complete pulse series applied to the chain. These pulses are then counted by a *Total Count Scaler* [11]), an electronic high speed counter, which displays the count with neon indicators for units and tens and a mechanical counter for hundreds etc. The count on the total count scaler should evidently correspond to the sum of the individual gating unit counts.

[11]) Of AERE design.

Associated with the total gating units is a *Fault Alarm System*. This stops the counting and sounds an alarm whenever a fault occurs in the gating unit chain. This is an essential feature, since a normal experiment takes several hours of usually unattended operation, and an audible fault alarm therefore avoids waste of experimental time.

To avoid frequent valve failures, the entire valve complement is normally replaced at periodic intervals. All circuits are designed to be independent of individual valve characteristics within the widest possible limits, so that readjustments are not necessary after valve replacements. These features are important since the equipment contains upwards of 750 valves.

The master timing unit

The master timing unit provides the series of timing pulses on which the operation of the spectrometer is based. A block diagram of the circuit is shown in *fig. 3*. For ease of reference, the different pulse series are detailed below.

1) A pulse series with a period of 2 μsec.
2) A pulse series with a period of 10 μsec.
3) A pulse series with a period of 100 μsec.
4) A pulse series with a period of 500 μsec.
5) The *principal recurrence frequency* (p.r.f.) pulse series, which governs the neutron pulse frequency, i.e. the fundamental recurrence period of the whole system. This period can be adjusted [12]) to 5000, 2500 or 1000 μsec.
6) A pulse series, having the same frequency as the p.r.f. pulse series, which is used to initiate the time base of the monitor on the linear accelerator and is called the *pre-pulse series*.
7) The *modulator pulse series*, already mentioned above. This series has also the same frequency as the p.r.f. series but has a variable delay of from 2 to 5 μsec on the pre-pulse series.

The minimum timing interval required in the system is 2 μsec and hence the timing system is based on a primary pulse series of 2 μsec period, synchronized by a 500 kc/s crystal controlled oscillator. The other pulse series are derived from the 2 μsec series by four frequency dividers. The frequency division ratios of these dividers are 5 : 1 (for the 10 μsec series), 10 : 1 (100 μsec), 10 : 1 (1000 μsec) and 5 : 1 (5000 μsec).

The 500 μsec and 2500 μsec series are derived from the combined pulse edges of both anodes of the last two dividers, as will be described presently.

The dividers are conventional two valve multi-

[12]) The 1000 μsec period is provided for future developments.

vibrators, synchronized by downgoing edges applied to both cathodes. For reasons which will be explained below (see *Delay units*, resetting of delay *III*) divider *I* divides by 5 unsymmetrically, one valve conducting for 4 μsec and the other for 6 μsec. This ensures that the 10 μsec pulse series is delayed by 6 μsec on the 100 μs pulse series. Dividers *II* and *III* divide by 10 symmetrically. Divider *IV* divides by 5 symmetrically. The latter is achieved by applying two sets of synchronizing edges, derived from the two anodes of divider *III*, separately to the two cathodes of divider *IV*, so that each valve conducts for two and one half periods, i.e. 2500 μsec.)

The dividers deliver square wave voltages with periods of 10, 100. 1000 and 5000 μsec. The 10 μsec and 100 μsec pulse series drivers are synchronized by the downgoing edges of the first two of these voltages. The 500 μsec pulse series driver is synchronized with the combined edges from the two anodes of divider *III*. This combination takes place in the *1000 μsec mixer*.

As already mentioned above, the period of the p.r.f. pulse series can be selected at 5000, 2500 or 1000 μsec. This pulse series is derived from the *p.r.f. selector*, which selects the edges from the appropriate dividers.

The pre-pulse series is derived directly from the primary pulse series by the p.r.f. selector which gates the next primary pulse occurring after the p.r.f. pulse.

The modulator pulse series is obtained from the pre-pulse series via the modulator pulse delay circuit, which provides a continuously variable delay of from 2 to 5 μsec.

All pulses are generated by output circuits which consist of blocking oscillators. The duration of the pulses is about 0.2 μsec, and their rise time is less than 0.05 μsec when the blocking oscillators work into a load consisting of a cable with a characteristic impedance of 100 ohms. As is shown in fig. 2, the first five of the pulse series mentioned are applied to the delay units, the latter two being applied to the main control unit for the linear accelerator.

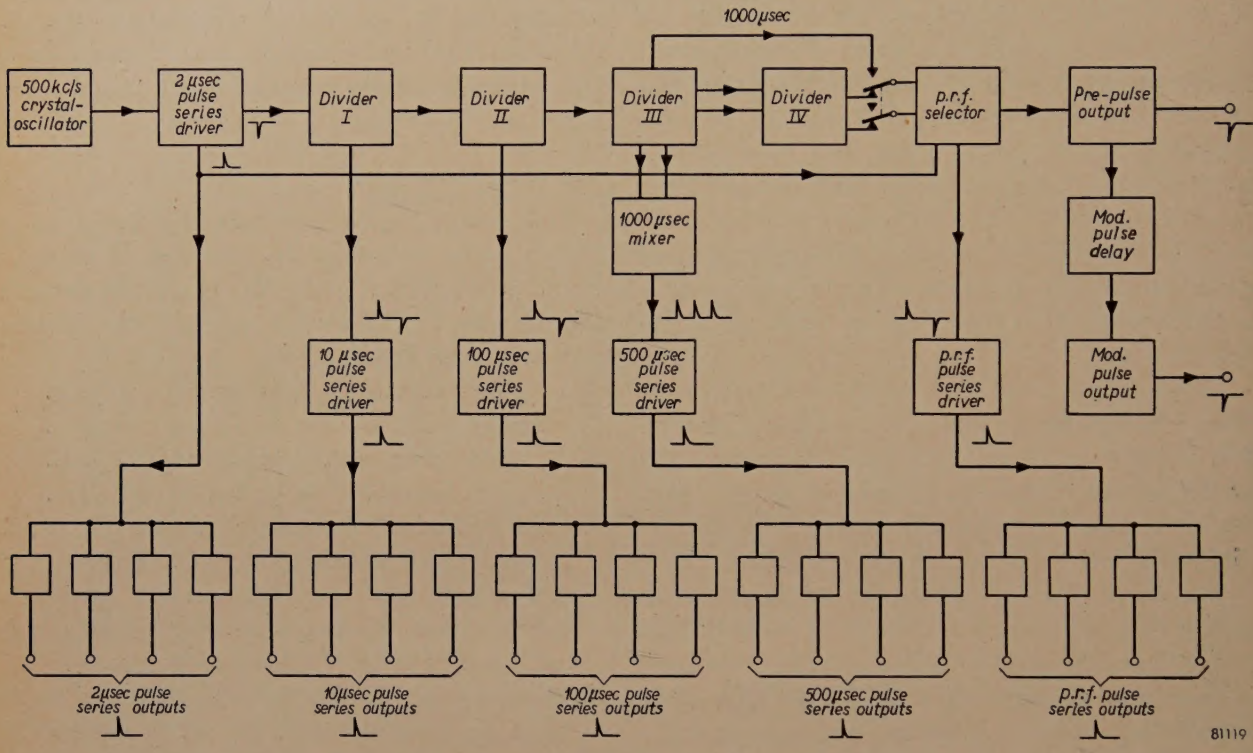


Fig. 3. Block diagram of the Master Timing Unit.

To allow for future development of the spectrometer by the addition of further flight paths, delay units and gating units, those of the pulse outputs which are connected to the delay units, are quadruplicated. Each set of four output stages is driven from a common driver.

The delay units

The delay units provide the time delay T between the initiation of the neutron pulse and the opening of the first gate in the appropriate chain of gates.

This delay is variable in 10 μsec steps from 0 to 2990 μsec.

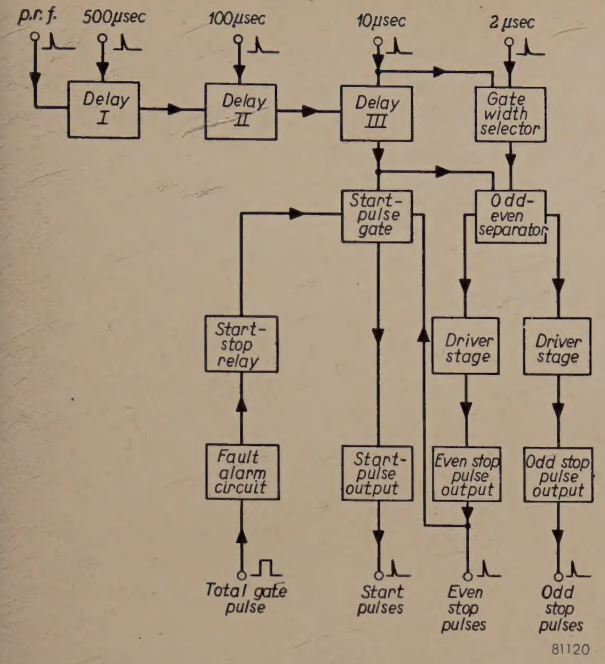


Fig. 4. Block diagram of a delay unit.

The delay units also apply three series of pulses to the gating unit chain. The first of these series is called the *start pulse series*, which initiates the gating unit chain; the others are the *odd* and *even stop pulse series* which establish the gating interval ΔT, and ensure that this interval is independent of the timing circuits of the individual gating units.

A block diagram of a delay unit is shown in *fig. 4*. The time delay T is provided by three delay circuits in cascade. Each of these circuits consist of a multivibrator which has a stable and a semi-stable state. The application of an initiating pulse triggers the multivibrator into the semi-stable state, and the duration of this state is controlled by a series of resetting pulses, which is continously fed to each multivibrator.

One example of a delay circuit is shown in *fig. 5* (delay *II*). When the circuit is in its stable state, B_1 is conducting and B_2 is non-conducting. The initiating pulses, which are provided by delay *I*, are applied to the cathode of B_2 (via terminal *p*). By these pulses the circuit is triggered into its semi-stable state with B_2 conducting and B_1 non-conducting. The resetting pulses are continuously applied to the cathode of B_1 (via terminal *r*). For this delay circuit the resetting pulses consist of the 100 μsec pulse series and hence the duration of the quasi-stable state is an exact multiple of 100 μsec. This multiple is determined by the value of resistance associated with the switch *S*.

Delay *II* applies downgoing initiating edges to delay *III* (via terminal *q*). As shown in fig. 5, at the "0" position of switch *S*, these edges are taken from the anode of B_2 and therefore in this position they coincide with the initiating pulses from delay *I*. In this position the circuit resets itself into the stable state prior to the first resetting pulse after the initiating pulse. At the other positions of *S* the initiating edges for delay *III* are taken from the screen grid of B_1 and so they are coincident with the moments of resetting. The delay time of delay II is therefore 0-900 μsec variable in 100 μsec steps.

All three delays operate in a similar manner. The initiating pulses and the resetting pulses for delay *I* consist respectively of the p.r.f. pulses and the 500 μsec pulse series. This circuit provides a delay of

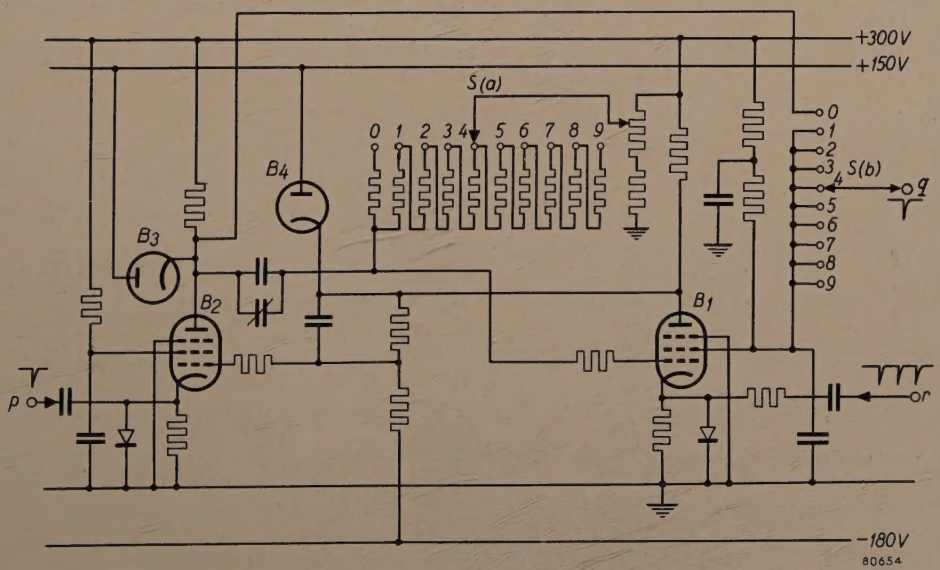


Fig. 5. Diagram of one of the delay circuits (delay *II*). It consists of a multivibrator with a stable and a semistable state.

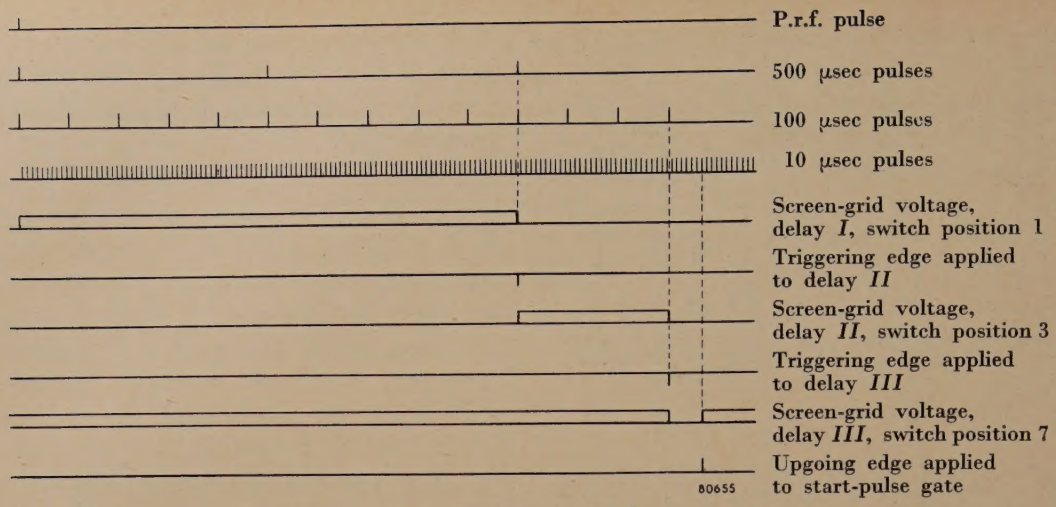


Fig. 6. Illustration of the effect of all three delay circuits in series. Delay I is set in switch position 1, delay II in position 3 and delay III in position 7. The total delay is therefore 1370 + 6 μsec minus the delay in the divider chain.

0-2000 μsec variable in two steps of 1000 μsec. The resetting pulses of delay *III* consist of the 10 μsec pulse series. As already mentioned this pulse series is delayed on the 100 μsec pulse series by 6 μsec, and as delay *III* is reset by resetting pulses in all switch positions, including the "0" position, the delay time of delay III is 6-96 μsec in 10 μsec steps.

Fig. 6 shows the effect of all the delay circuits in series. As the extra delay of 6 μsec mentioned above is not indicated on the switch positions of delay *III*, the edge which is available from delay III is delayed on the p.r.f. pulse by the sum of the three individual delay settings plus 6 μsec and minus the overall delay in the divider chain. This latter delay is approximately 1·5 μsec. It is useful as it prevents coincident triggering of the delay circuits, as all the initiating pulses occur a fraction of a microsecond after the resetting pulses. Coincident triggering can be a serious fault as it tends to render the circuit inoperative.

The way in which the start pulses and the stop pulse series are produced is illustrated in the *figures 7a and 7b* which relate respectively to gating intervals of 2 and 10 μsec. To prevent coincident triggering of the gating units it is necessary to produce two series of stop pulses, designated the odd and even stop pulse series, feeding the odd and even gating units respectively. This is accomplished by the odd-even separator consisting of a direct-coupled multivibrator, which in the case of 2 μsec

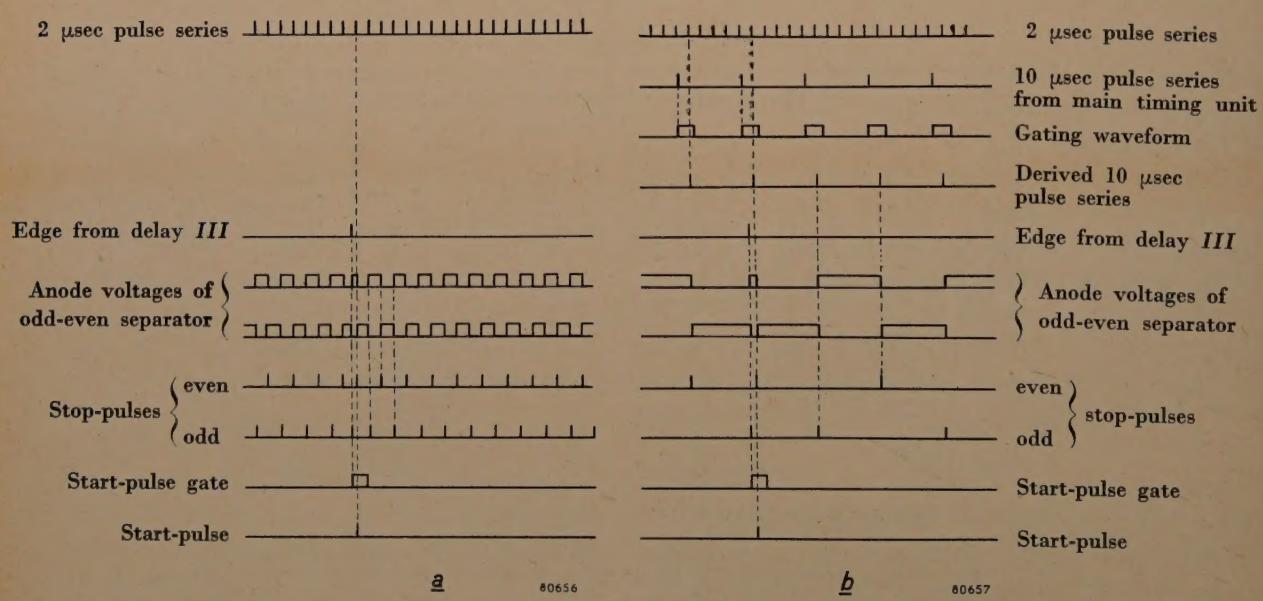


Fig. 7. Illustration of the way in which the start and stop pulses are produced *a*) in the case of a gate width of 2 μ sec, *b*) in the case of a gate width of 10 μ sec.

gate width is driven by the 2 μsec pulse series from the main timing unit. The edges in the respective anodes of the odd-even separator are used to trigger the odd and even stop pulse driver blocking oscillators.

phasing of the 10 μsec pulse series with respect to the pre-pulses, and 2 μsec by the gating of the even stop pulses. Hence, with all delays set at zero the start pulses and the neutron pulses can be made coincident in time by aligning the leading edges of

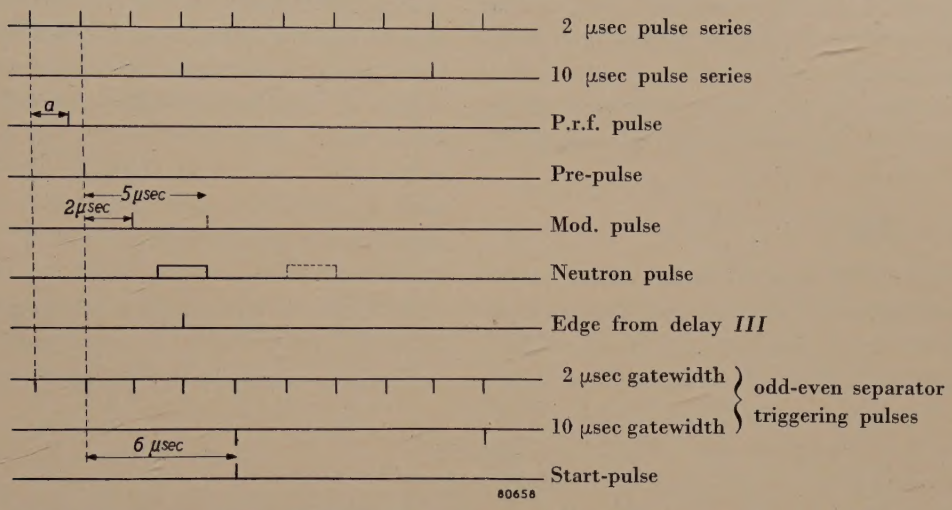


Fig. 8. Illustration of the phasing of the start pulses and the neutron pulses when all delay circuits are in the zero position.

The start pulse, which initiates the gating unit chain is derived from the even stop pulse series. The edge from delay *III* is used to produce a gating waveform, called the start pulse gate, which gates the next even stop pulse. This triggers the start pulse output blocking oscillator. It is necessary to place the stop pulses correctly with respect to the edges from delay III. This is accomplished by setting the odd-even separator in the right condition with the edges from delay *III*.

When a gate width of 10 μsec is desired (fig. 7*b*) the odd-even separator is not driven by the 10 μsec pulse series from the main timing unit, but by a 10 μsec series which is derived from the 2 μsec pulse series by gating the appropriate pulses. The waveform which accomplishes this gating is controlled by the 10 μsec pulse series from the main timing unit.

The phasing of the start pulses and the neutron pulses is illustrated in *fig. 8*. The modulator pulses are delayed on the pre-pulses by a delay which is continuously variable from 2 to 5 μsec. The modulator itself introduces a delay of from 1 to 3 μsec. The neutron pulses can therefore be delayed on the pre-pulse from 3 to 6 μsec with a modulator delay of 1 μsec, or from 5 to 8 μsec with a modulator delay of 3 μsec. With all delays set at zero the start pulses are delayed with respect to the pre pulses by 6 μsec. Of this, 4 μsec is contributed by the

the start pulse and the linear accelerator electron pulse. Any delay T now introduced by the delay circuits will be accurately defined by the setting figure of these circuits.

The circuit used for establishing the variable time delay of the modulator pulses with respect to the pre-pulses is illustrated in *fig. 9*. The two triodes of B_1 are strapped in parallel and are normally conducting. At a time coincident with the pre-pulse, both valves are rendered non-conducting

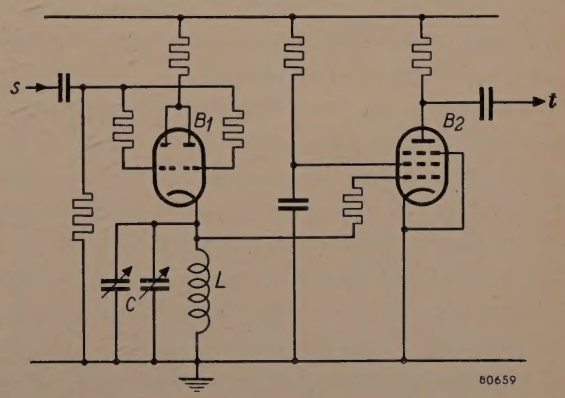


Fig. 9. Circuit diagram of the modulator pulse delay cricuit. The delay time is controlled by the LC circuit in the cathode lead of B_1.

by a downgoing edge applied to terminal *s*. A sinusoidal voltage is developed across the tuned circuit which forms the cathode load. Since in the first half cycle the cathode of B_1 is negative with

respect to earth, B_2 which is normally conducting is rendered non-conducting. At the conclusion of the first half-cycle B_2 is again driven into conduction and the downgoing edge in the anode is used to trigger the blocking oscillator which generates the modulator pulses. The waveform then tries to drive the control grid of B_2 positive and the resultant grid current damps out the sinusoidal voltage at the cathode of B_1. The delay between the pre-pulses and the modulator pulses is controlled by the tuning frequency of the cathode circuit of B_1, which can be varied by adjusting the tuning capacity.

The gating unit chain

The requirement of the gating unit chain is that the individual units shall be rendered operative for successive intervals ΔT of 2 or 10 μsec. To achieve this, every unit is provided with a series of stop pulses, odd or even depending upon its position in the chain. After the delay T, the start pulse opens gating unit number one which is closed by the next odd stop pulse a time ΔT after the start pulse. The closing of gating unit number one is accompanied by the generation of a pulse, called a "start-out" pulse, which opens gating unit number two. Number two is closed by the next even stop pulse after the interval ΔT and opens number three. Each unit therefore provides a pulse to open the next unit and the units are rendered operative for successive intervals ΔT.

Each individual gating unit incorporates a gating waveform generator, a gating valve, a start-out pulse generator and a register pulse generator (*fig. 10*).

The gating waveform generator consists of a direct coupled multivibrator with two stables states. It is normally held in one stable state by the application of the stop pulse series. The start pulse triggers it to the other stable state and the next stop pulse triggers it back to its normal stable state. It thus provides a square wave of duration ΔT equal to the interval between the start and the stop pulse.

This square wave or gating waveform is applied to the control grid of the gating valve. All the signal pulses derived from the detection chamber are applied to the suppressor grid. Hence each gating valve passes to its anode any signal pulses arriving during its gating interval ΔT.

The gated signal pulses are of too short a duration to operate a mechanical counter, and they are therefore used to trigger the register pulse generator, which is a cathode-coupled multivibrator with a stable and a semi-stable state. The duration of the semi-stable state is arranged to be 70 μsec and is used to operate a high speed relay which in turn operates the appropriate mechanical counter on the register desk. No scaling units are required as the probability of two signal pulses being gated by a particular gate during 70 μsec is extremely remote.

The screen grid of the gating valve is connected to a pulse generating circuit consisting of an 85 μH choke in parallel with a crystal diode. This circuit generates a positive pulse when the current in the gating valve is cut off at the termination of the gating interval. This pulse is fed to the next gating unit via a cathode follower.

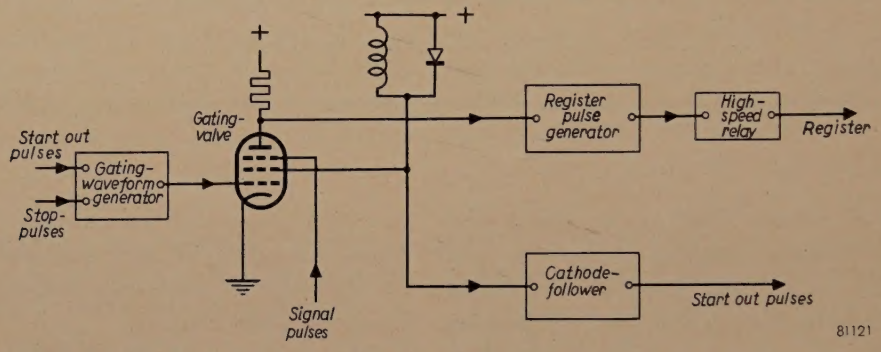


Fig. 10. Schematic diagram of a gating unit. (The first gating unit is opened by the start pulses instead of the start-out pulses.)

The total gating unit, provided at the end of each chain of gating units, is opened by the initial start pulse and closed by the start-out pulse from the last unit in the chain. It therefore gates all the signal pulses, gated by the individual units in the chain. The gated pulses are counted by the total count scaler and provide a check on the experimental results.

The duration of the total gating waveform is the sum of the gate width of the chain of gates associated with it and is used to operate the fault alarm system. Any failure in the start pulses, stop pulses or an individual gate will render the total gate inoperative. The resultant absence of the total gating waveform causes the fault alarm circuit to stop the counting and sound an audible alarm.

Accuracy of the measurements

Assuming correct operation of the frequency dividers and delay circuits, the accuracy of the electronic system is dependent upon the principal timing pulses of which all except the modulator pulses are derived directly from the 2 μsec pulse series. As this primary pulse series is derived from a crystal controlled 500 kc/s oscillator, the timing errors contributed by the principal timing pulses will be very small (less than 0.1 μsec).

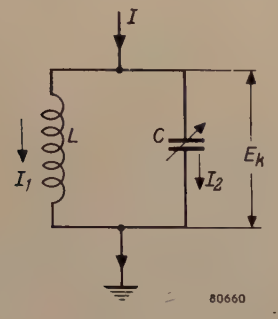


Fig. 11. Cathode circuit of valve B_1 of the modulator pulse delay circuit (fig. 9) showing the notation used in the calculation of the delay time.

Any variation in the relative phasing of the pre pulses and the modulator pulses will contribute to the inaccuracies of the electronic system, since the operation of the gating units is referred to the primary pulse series in the same way as the pre-pulses (see fig. 8) and the accelerator is actuated by the modulator pulses. The accuracy of the time delay which is provided by the modulator pulse delay circuit (fig. 9) will now be calculated.

An equivalent circuit of the cathode circuit of the valve B_1 is shown in *fig. 11*. The valve provides a current I, where $I = I_k$ when $t < 0$, and $I = 0$ when $t > 0$.

The circuit equations are:

$$-L\frac{dI_1}{dt} = \frac{q}{C}, \quad I = I_1 + I_2 \text{ and } \frac{dq}{dt} = -I_2,$$

where q is the charge of the capacitor C. Eliminating I_1 and I_2:

$$\frac{q}{LC} + \frac{d^2q}{dt^2} = 0,$$

so that for $t > 0$ we get:

$$E_k = \frac{q}{C} = -I_k\sqrt{\frac{L}{C}}\sin\frac{t}{\sqrt{LC}}.$$

As the modulator pulse is delayed with respect to the pre-pulse by half a cycle of E_k, this delay time amounts to $T_d = \pi\sqrt{LC}$ and the amplitude of E_k is $I_k\sqrt{L/C}$.

The accuracy of the time delay is dependent upon the grid voltage at which B_2 starts to conduct and upon the stability of the inductance and capacity of the tuned circuit. Measurements on samples of the pentode used (type EF 91) indicate that the spread in control-grid cut off potential is dependent on the screen grid potential, becoming smaller as the screen grid potential is deereased. With a screen grid potential of 150 V the spread in cut off potential is from 3 to 4·5 V.

The slope of the waveform at any time t is given by

$$\frac{dE_k}{dt} = -\frac{I_k}{C}\cos\frac{t}{\sqrt{LC}}.$$

Hence, at the instant when B_2 becomes conducting ($t = \pi\sqrt{LC}$) the slope is equal to I_k/C. The capacity C is variable between 88 and 345 pF. As $I_k = 19$ mA we obtain for the slope of the waveform a value of 217 V/μsec for the minimum value of C, and a value of 55 V/μsec for the maximum value of C. The possible variation in the control-grid cut off poten-

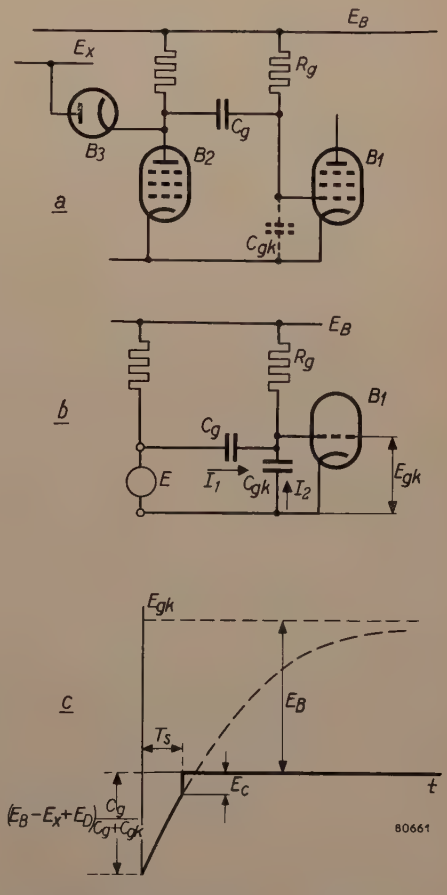


Fig. 12. *a*) Simplified diagram of a part of one of the delay circuits (fig. 5).
b) Equivalent diagram of fig. 12*a* in which the valve B_2 has been replaced by a voltage source E generating a step function voltage.
c) The voltage E_{gk} between grid and cathode of B_1 as a function of time.

tial of B_2 will thus cause at most a variation in the minimum delay time of 0·007 μsec or 0·35% and a variation in the maximum delay time of 0·027 μsec or 0·54%.

The stability of the inductance is almost solely dependent on the temperature coefficient of the permeability of its Ferroxcube core. This is quoted as 120 parts in a million per degree centigrade. The corresponding variation in delay time is therefore 0.12% for a 20°C variation in temperature.

The capacity is made up of the following: a two gang variable tuning condenser, the input capacitance of B_2, the heater to cathode capacitance of B_1, the coil capacitance, the wiring capacitance and the two valve-base capacitances. The coil capacity, the wiring capacities and the valve-base capacities are substantially constant for a particular assembly. The stability of the variable capacity is better than 0.1%. The input capacity of an EF91 and the heater to cathode capacity of both parts of an ECC81 are subject to a variation of ± 1pF. The minimum capacity is therefore subject to a maximum variation of 3 pF in 88 pF giving a variation in delay time of 1.71%. The maximum capacity is subject to the same variation with a corresponding delay time variation of approximately 0.44%.

The overall accuracy of the time delay is therefore 1.20% or 0.06 μsec at maximum delay time and 2.28% or 0.046 μsec at minimum delay time. Since the overall uncertainty of the electronic system is determined by the 2 μsec gate width, a maximum variation of 0.06 μsec contributed by the modulator pulse will have little effect.

Reliability of the installation

The reliability of the spectrometer depends upon the correct operation of the multivibrator dividing and delay circuits. The timing function of the multivibrator is governed by its semi-stable state and an examination of the factors governing this state is therefore required.

In *fig. 12a* a simplified diagram of a part of fig. 4 is shown. During the stable state, when B_1 is conducting, the flow of grid current in this valve keeps its grid-cathode potential approximately at zero. At the moment where the initiating pulse is applied to the cathode of B_2 the anode potential of this valve drops from E_B to $E_X - E_D$, where E_D is the anode-cathode potential of the clamping diode B_3 and the control grid potential of B_1 (V_{gk}) falls to a negative value

$$(E_B - E_X + E_D)\frac{C_g}{C_g + C_{gk}} .$$

E_{gk} then increases as is shown in figure 12*c* till in the absence of resetting pulses it reaches a certain critical value E_c when the circuit will reset itself into the stable state.

Assuming that the time for the anode potential of B_2 to decrease from E_B to $(E_X - E_D)$ is small compared with the duration of the semi-stable state, B_1 can be replaced by a voltage source generating a step function E as shown in the equivalent circuit in figure 12*b*.

The equations governing the circuit are:

$$E_B - E = \frac{q_1}{C_g} + (I_1 + I_2) R_g,$$

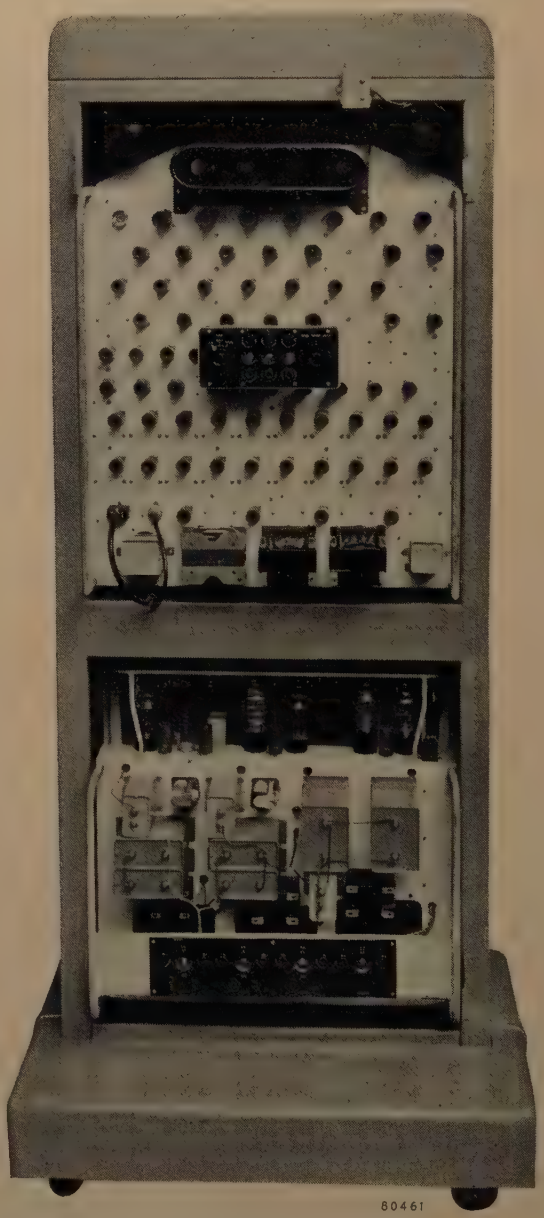


Fig. 13. The master timing unit. Front view with covers removed, showing the valve side of the main chassis (top) and the power unit (bottom).

$$E_B = (I_1 + I_2)\, R_g + \frac{q_2}{C_{gk}},$$

$$I_1 = \frac{dq_1}{dt},$$

$$I_2 = \frac{dq_2}{dt},$$

where q_1 and q_2 are the charges of C_g and C_{gk} respectively.

From these equations an expression is obtained for the voltage E_{gk}:

$$E_{gk} = \frac{q_2}{C_{gk}} = \left\{\frac{(E_B - E)C_g}{C_g + C_{gk}} + E_B\right\} \times \left\{1 - \exp\left(\frac{t}{(C_g + C_{gk})R_g}\right)\right\} - \frac{(E_B - E)\,C_g}{C_g + C_{gk}},$$

or, as $C_g \gg C_{gk}$,

$$E_{gk} = (2E_B - E)\left\{1 - \exp\left(\frac{-t}{C_g R_g}\right)\right\} - (E_B - E).$$

If we denote the time for E_{gk} to reach the critical value E_c by T_s,

$$T_s = -C_g R_g \log_e \left\{\frac{E_B - V_c}{2E_B - E}\right\},$$

where $E = E_X - E_D$.

The way in which T_s depends on the stability of the factors determining T_s can now be deduced. The actual circuit conditions are $E_B = 300$ V, $E_X = 150$ V, E_D varying from 1.0 to 3.6 V, and E_c varying from 3.4 to 4.6 V. E_B and E_X are provided by stabilized supplies of expected maximum variations of 1%. With the values mentioned we calculate that a variation of 1% in E_B or in E_B gives a variation of 0.8% in T_s.

A variation of E_D from 1.0 to 3.6 V gives a variation of 2.4% in T_s and a variation of E_c from 3.4 to 4.6 V gives a variation in T_s of 1.1%.

A variation of $C_g R_g$ is in general caused by the resistor. For high stability resistors up to 1 megohm a stability of 2.5% can be realized.

Fig. 14. The main assembly. Front view showing in the centre the register and control desk. At the top of the left and right sections are the delay unit monitor tubes; below them are the delay unit control panels. Half way down on the left section is a total count scaler (on the right there is a position for another scaler). At the bottom. left and right, are the power supply control panels.

It follows from these calculations that the duration of the reset time of each multivibrator circuit is subject to a variation of maximum value 7.6 %. Should this variation exceed the period between the resetting pulses, the danger arises that the circuit might be reset into the stable state by a wrong pulse. When the division ratio is 10, this being the maximum value occurring in the installation, the permissible variation in T_s in this respect is 10%, which is not exceeded by the figure calculated above.

mounted in the top of the rack which draw air in through a grid at the bottom. Vertical mounting of the chassis is employed so that they can be maintained without removal from the rack. *Fig. 13* shows a front view of the master timing unit with the covers removed.

The main assembly consists of two racks mounted on either side of the register desk. Each rack houses a delay unit, a total count scaler, and four power supplies, each rack again being cooled by two fans mounted in the top of the rack and drawing air

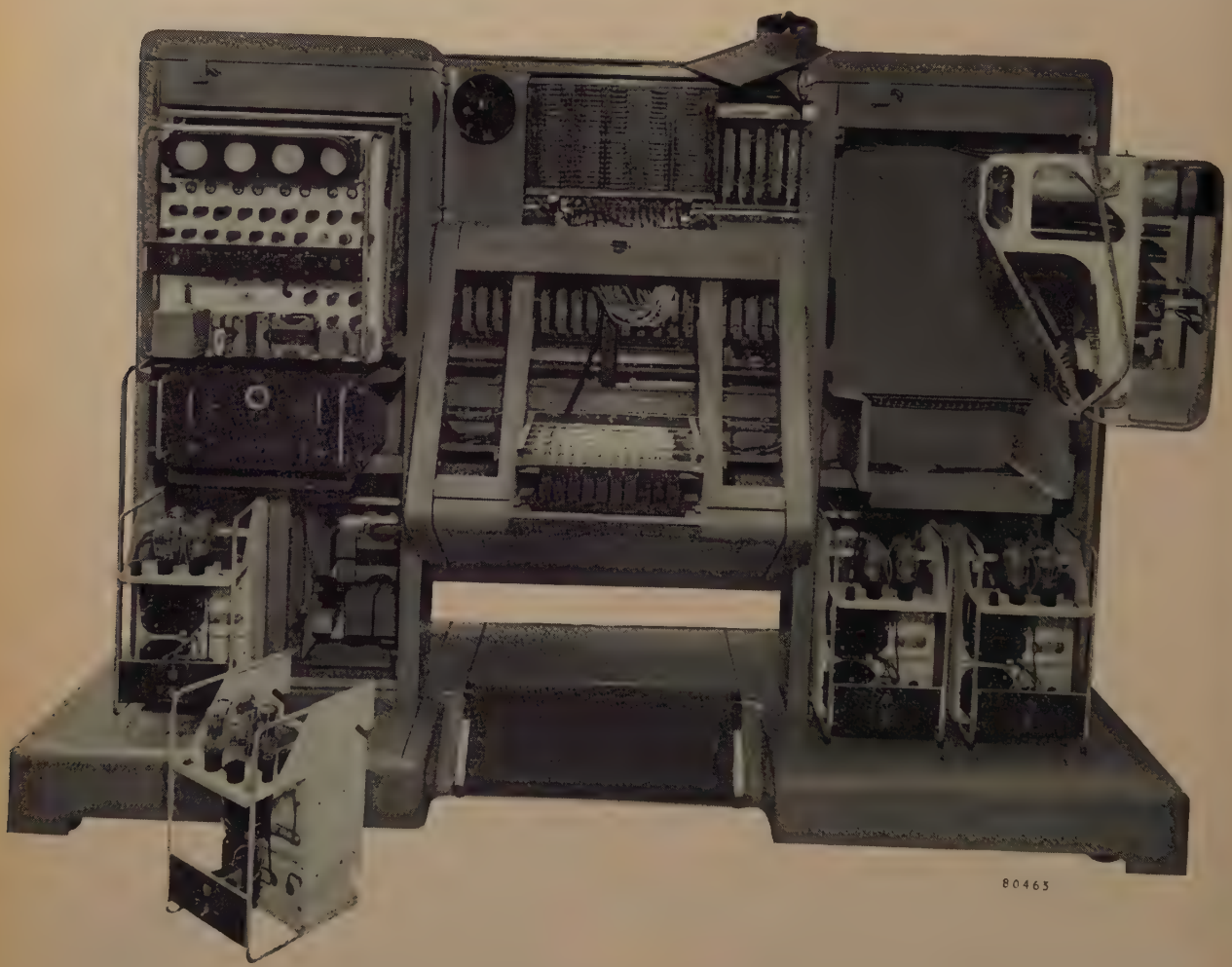


Fig. 15. The main assembly. Front view with covers removed. The right hand delay unit shows the hinged mounting framework and the input connections. One of the power supplies has been removed to show the method of mounting. The register desk has been hinged down and one of the fans has been removed, so that the rear side of the gating unit rack is visible.

Construction of the equipment

As the master timing unit is designed to feed timing pulses to four sets of delay units, it is housed in a separate rack together with its associated power supplies. The timing pulses are brought out to a series of coaxial sockets mounted on a channel at the foot of the equipment. Cooling is effected by two fans from the bottom. The delay units are mounted vertically in a hinged frame so that they can be maintained without removing them from the rack. A.C. supplies to, and D.C. supplies from each unit are brought to four tag boards mounted on either side of each rack. *Fig. 14* and *15* show the main assembly with and without covers.

The gating unit rack, which is shown in *fig. 16*, is wired as a separate unit and is supported on the back of the main framework by four brackets. In consists of 103 frames designed to take 100 gating units and 3 total gating units. Each frame is fitted with 11 spring loaded contacts to take the input and outputs to and from each unit. This provides for immediate rectification of faults in the gating unit chain as all the units are interchangeable and any faulty unit is easily replaced by one of the spare units.

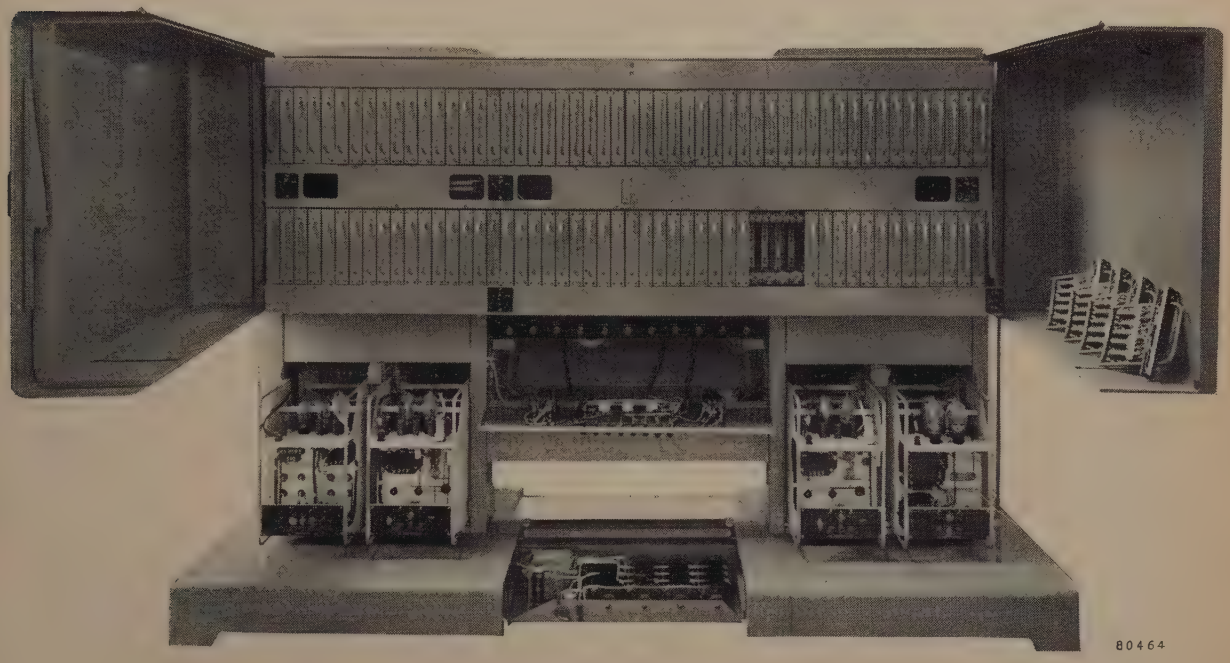


Fig. 16. The main assembly. Rear view with covers removed, showing the grating unit rack which houses 100 gating units and three total gating units. Four of the units have been removed and are lying in the right hand cover. The main input panel in the centre has been hinged down to show the main contactors. Power packs are also visible (bottom left and right). In the centre of the base is the 50 V power supply for the register desk.

The five switches dividing the rack into two separate chains of gating units are housed at the appropriate points along the bus bars which feed the start and stop pulses to the units. Cooling is effected by fans, two housed above the ends of the rack and the other two mounted horizontally drawing air from the central portion of the rack and blowing it out from the front of the unit. In order to ensure that the air circulates through the gating units, the whole rack is enclosed by two covers hinged at the end and having a wire mesh running along the bottom flange. The maximum temperature rise using this arrangement is 35 °C above ambient.

The register desk with its 100 mechanical counters is mounted at an angle to facilitate reading of the numbers. Connections from the registers to the gating units are made by a cable form wired onto a tag board on the back of the gating unit rack. Also incorporated in the register desk are the count keys, the fault alarm and the A.C. input switches.

The timing pulses are fed from the master timing unit by 100 Ω coaxial cables to coaxial sockets mounted at the back. Each cable is terminated by a 100 Ω resistor. The A.C. inputs are taken in via a hinged input panel mounted below the pulse inputs. A.C. switching is accomplished by two gravity return contactors. In order to ensure that the gating units are not operated without their bias supply, the contactor switching the A.C. to the power supplies is operated via a relay which in turn is operated by the bias supply.

The covers, with the exception of the gating unit rack covers, are fitted with interlock switches wired in series with the operating coil of the H.T. main contactor.

The electronic assembly can be seen in the background on the photograph of fig. 1, which gives a general view of the whole installation.

Acknowledgements

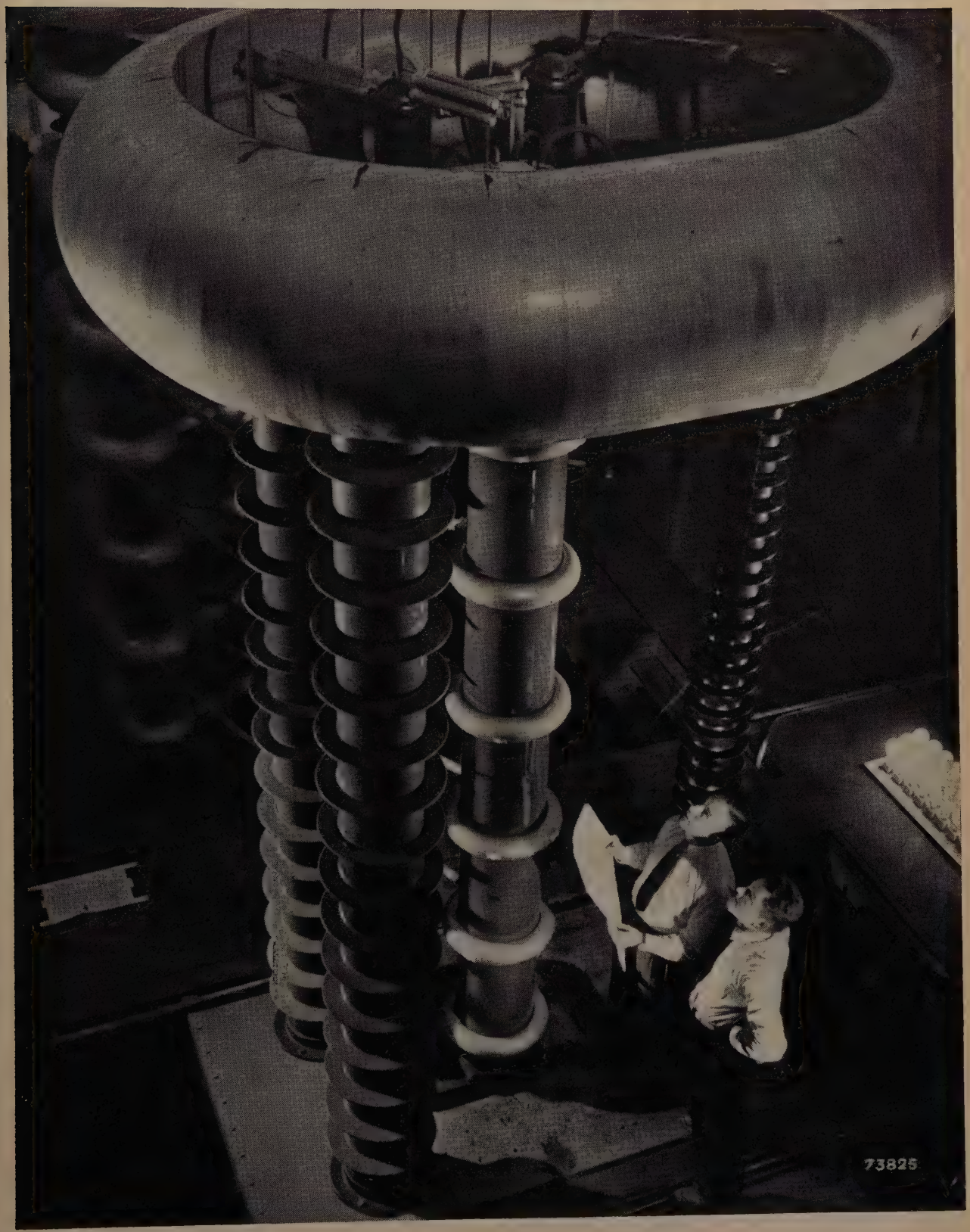
The authors wish to acknowledge the help of their colleagues at the Mullard Research Laboratories and of members of the Electronic and Nuclear Physics Divisions at A.E.R.E. during the course of the

development reviewed and in the preparation of this article. Thanks are also due to the Director of A.E.R.E. and to the Directors of the Mullard Valve Company for permission to publish this article.

Summary. In this article a description is given of a time-of-flight neutron spectrometer installed in the Atomic Energy Research Establishment at Harwell and used for measurements of the energy levels of neutron scattering and resonance absorption. The heart of the installation is the 15 MeV linear accelerator previously described in these pages. A 2 μsec electron pulse after travelling down the accelerator is used to irradiate a γ-ray and neutron source. Some of the liberated neutrons travel down a 20m flight path, after which they have become spaced out in time according to their energies. The installation contains two of these flight paths, which can be used separately for independent experiments. At the end of each flight path the neutrons are detected by a neutron detector. The electrical signal pulses from this chamber constitute a series whose distribution in time corresponds to the energy spectrum. This pulse series is fed to the input rail of a bank of 100 gating units, which are opened successively for equal short intervals ΔT starting with a time delay T from the initiation of the neutron pulse. Each gating unit output is fed to a mechanical counter. The intervals ΔT can be set at 2 or 10 μ sec and the delay time T is adjustable between 0 and 2990 μ sec. The principal recurrence frequency can at present be set at 200 or 400 p.p.s.

The functioning of the installation is based on a number of timing pulse series which are generated in the master timing unit. They are all controlled by a primary pulse series of 2 μ sec period derived from a 500 kc/s crystal controlled oscillator. The other pulse series are derived from this primary series by four frequency dividers (multivibrators). The time delay T is provided by a delay unit which contains three adjustable delay circuits in cascade. Each of these circuits consists of a multivibrator with a stable and a semi-stable state. Each gating unit contains a multivibrator with two stable states, which is triggered by two series of pulses, the start out pulse series and the stop pulse series. To prevent coincident triggering, two series of stop pulses are used, feeding the odd and even gating units respectively. The 100 gating units can be used either in a single sequence or in two independent banks for experiments on both flight paths. To provide a check on the correct operation of the installation a total gating unit is provided for each sequence of gating units. Associated with these total gating units is a fault alarm system which sounds an alarm whenever a fault occurs in a gating unit sequence. Since a normal experiment takes several hours of (usually) unattended operation, this alarm avoids waste of experimental time. At the end of the article some calculations are made concerning the accuracy and the reliability of the installation and a short description is given of some constructional details.

EXPERIMENTAL SET-UP OF A 1 MILLION VOLT ION-ACCELERATING TUBE



A source of hydrogen or deuterium ions is mounted in the top protecting cover, supported by three columns. The ions are accelerated in the 4 metre-long acceleration tube (centre). The cascade generator, supplying the acceleration voltage of 10^6 V, is visible in the background.

PHOTOGRAPHY OF THE EYE WITH THE AID OF ELECTRONIC FLASH-TUBES

by J. E. WINKELMAN *) and N. WARMOLTZ.

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The electronic flash-tube, apart from its extremely short flash duration, good light output and high efficiency, possesses other important characteristics. One of these is the great variety of shapes in which these tubes may be constructed; another is their flexibility in operation. These characteristics are illustrated by the special flash-tube for ophthalmic puposes described in this article, which makes it possible, in a simple set-up, to obtain excellent well-defined colour photographs of the human eye.

In ophthalmology, photographic records of patients nowadays occupy an important place. Well-defined photographs, particularly those in colour, provide a far more complete record than the sketches on which the ophthalmologist formerly had to rely.

In this article we shall deal with an apparatus for eye photography that has been developed in the Wilhelmina Hospital ophthalmic clinic in Amsterdam. This apparatus serves for photographing the externally visible parts of the eyeball (the anterior segment) which includes (*fig. 1*) the cornea, the sclerotic coat or white of the eye, the conjunctiva, the anterior chamber, the iris, the pupil, the anterior surface of the lens, the eyelids and the adjoining skin, and parts of the lachrymal apparatus. *Fig. 2* shows four colour photographs made with the present equipment of the eyes of different patients. For photographing the posterior segment of the eye (the fundus oculi, including the retina), different set-ups are used, which will not be dealt with in this article.

As a photographic object the eye, in particular the diseased eye, presents considerable difficulties. Abnormalities of the eye are as a rule of very small dimensions, so that at least full-scale photographs are required. For this the camera has to be brought up very near to the object, which in turn requires the use of a very small aperture in order to produce the necessary depth of focus. If we consider, moreover, the relatively low sensitivity of colour film, then it will be clear that photographs of this kind require a large quantity of light. Even for the most powerful sources of contiuous illumination, this involves fairly long exposure times, e.g. some seconds. Difficult as it may be to keep a normal, healthy eye from moving during such a period, for a diseased eye this is well-nigh impossible.

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An almost ideal solution of this problem was found in the electronic flash-tube. This light source, originally developed for highly specialized purposes [1]), but now generally applied in photography [2]), is commercially available in a number of forms. It consists basically of a glass tube, filled with rare gas at not too low a pressure, through which a

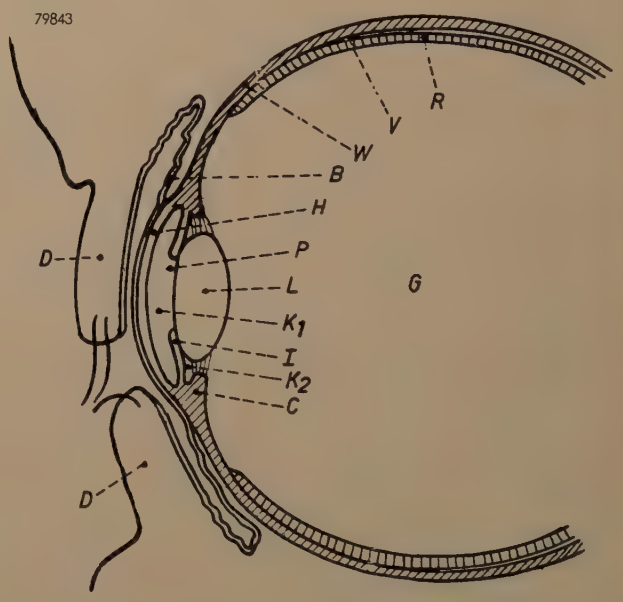

Fig. 1. Cross-section of the anterior segment of the eye. *D* eyelids, *H* cornea, *W* sclerotic coat or white of the eye, *B* conjunctiva, *L* crystalline lens, *I* iris, *P* pupil, K_1 anterior chamber. Also shown are, K_2 posterior chamber, *C* ciliary muscle, *V* choroid, *R* retina, *G* vitreous humour.

[1]) See e.g., S. L. de Bruin, An apparatus for stroboscopic observation, Philips tech. Rev. **8**, 25-32, 1946: N. Warmoltz and A. M. C. Helmer, A flash lamp for illuminating vapour tracks in the Wilson cloud chamber, Philips tech. Rev. **10**, 178-187, 1948.

[2]) Cf. e.g. Photogr. J. **89B**, May-June 1949 (symposium on electronic flash lamps), or: M. Laporte, Les lampes à éclaire lumière blanche et leurs applications, Gauthier-Villars, Paris 1949. (A comprehensive article on electronic flash-tubes will appear in the next issue of this Review — Ed.)

capacitor is made to discharge via two electrodes with the aid of a triggering electrode. A flash is thus produced, having a duration varying between a few microseconds and a few milliseconds, dependent on the construction of the lamp, and of such a high intensity that the total light output emitted amounts to some thousands or some tens of thousands of lumen seconds. During such extremely short periods the eye shows no discernible reaction to the illumination: this occurs later, when the photograph has already been made. The luminous efficiency of electronic flash-tubes is considerable (of the order of 40 lumen/watt), so that no excessive demands are made on the electrical supply unit. When compared with ordinary flash-bulbs, for this particular application, the electronic flash-tube has the advantage that it develops hardly any heat (to which some eye patients may be extremely sensitive). Furthermore, a series of exposures need not be interrupted for the exchanging of the bulbs. Finally, the flash-tube allows a simple solution to a very important aspect of this particular application — the setting up and focussing of the camera (see below).

In principle, various commercially available flash-tubes are suitable for the purpose described here and there have already appeared several publications on set-ups of this kind [3]). The apparatus

Fig. 2. Colour photographs of the eyes of different patients, made with the apparatus described, on daylight colour film (for use with a source of colour temperature 6000-6500 °K).
a) Normal eye. Note the excellent reproduction of the texture of the iris.
b) Eye in diabetes. Fine blood vessels can be seen running across the iris.
c) Eye with dendritic keratitis in the cornea. The dendritic ulcus of the cornea is coloured green with fluorescein.
d) Eye with loosened and displaced lens. On top the dark pupil is visible and below it the sagging, turbid lens.

[3]) See e.g., R.R. Trotter and W. M. Grant, Electronic flash (gas-dicharge) tube in photography of the anterior segment of the eye, Arch. Ophthalm. **40**, 493-496, 1948; N. Jeffreys, Problems of ophthalmological photography, J. Phot. Sci. **1**, 184-192, 1953 (Nov.-Dec.); G. Meyer-Schwickerath, Flash photography of the diseased eye, Photographie u. Forschung **5**, 170-173, 1953 (June).

developed in Amsterdam, however, was based on the assumption that a simple but effective set-up could best be realized by adapting the light-source to the specific requirements of this particular application. These requirements may be outlined as follows. The object to be photographed is very small — its diameter will not exceed 4 or 5 cm. In order to concentrate a substantial portion of the light of the flash tube on to such a small area by means of a lensor mirror of reasonable proportions, the flash tube should preferably be very small. Furthermore, in order to obtain a uniform illumination of the curved surface of the eye and to direct a sufficient amount of light on the iris, the light source must be placed as near as possible to the line of sight of the camera. This also requires that the source should be of small dimensions. Finally the possibility of undesirable reflections must be considered both from the cornea, which acts as a convex mirror, and from the conjunctiva. This can best be avoided by a set-up permitting a prior examination of the location of the reflections. Such an examination is possible with the aid of an auxiliary light-source, so arranged to illuminate the eye from exactly the same angle as the subsequent flash. For this purpose a filament lamp may be used, of low intensity to avoid discomfort to the patient.

All these considerations have led to the construction of the special flash-tube shown in *fig. 3*. It consists of three almost co-planar turns of rather narrow glass tube. In the centre of the spiral is an aperture approximately 1 cm in diameter. For the auxiliary lamp an experimental type of reflector lamp has been chosen which has an internal ellipsoidal mirror. This produces an image of the filament about 2 cm outside the bulb. The reflector lamp is so positioned behind the flash-tube that the image of the filament is produced within the aperture of the spiral. This image and the flash-tube are projected by means of a "Perspex" condenser lens on the eye to be photographed (*fig. 4*). The outside of the condenser is provided with a sheet of ground glass, to provide some dispersion of the light, as otherwise the structure of the source would show up on the object.

The whole lighting system is contained in a casing, mounted close to the camera on a single stand (*fig. 5*). The camera is of the 35 mm-type, provided with a mirror-reflex attachment (lens f 3.5, with a focal length of 5 cm). The distance from the lens to the patient's eye is normally 6 to 7 cm, producing a photograph about 1.5 times full size. The flash-tube is supplied from a 4 μF capacitor, charged up to about 5 kV, so that the flash energy amounts to roughly 50 joules. Nothwithstanding this relatively small energy, the illumination of the object is sufficient to allow the use of apertures of f 16 and even

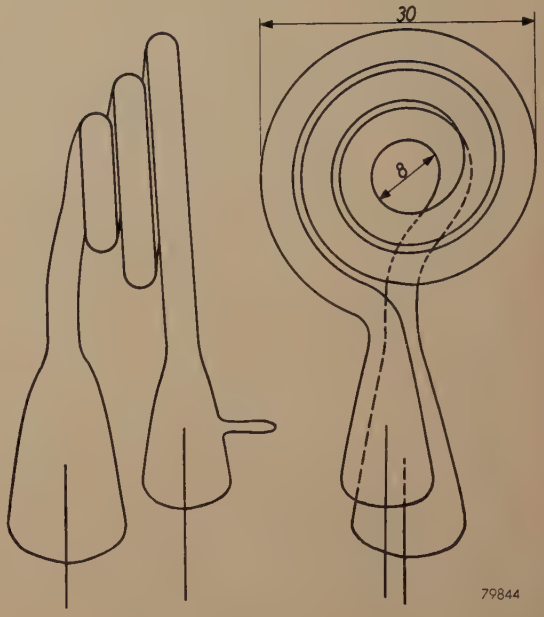

Fig. 3. Sketch of the electronic flash-tube developed for eye photography. The glass spiral has a central aperture of about 8 mm diameter.

smaller. The colour temperature of the flash-tube is approximately 6500 °K, corresponding to normal daylight, so that daylight colour film can be used.

The flash is normally triggered by contacts in the camera synchronized with the shutter, but the apparatus can, if necessary, also be used with a camera without electronic-flash synchronizing contacts. For this purpose a pedal switch is provided which successively switches off the auxiliary lamp, opens the camera shutter and triggers the flash.

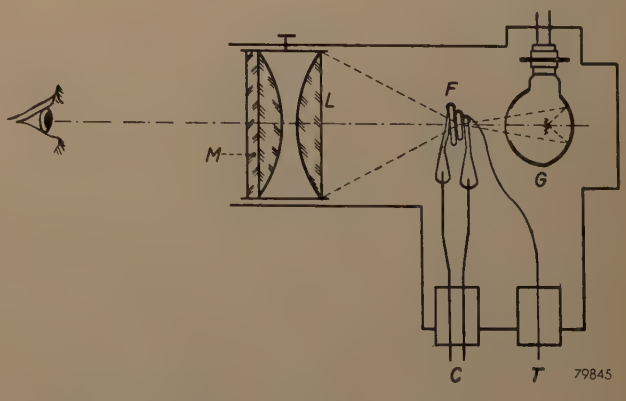

Fig. 4. The illumination system for eye photography. F electronic flash-tube, L lens, M sheet of ground glass. G is a filament lamp for focussing and sighting; its silvered bulb produces an image of the filament outside the envelope and the lamp is so positioned that the image falls within the central aperture of the flash-tube. C connections to capacitor, T lead for triggering pulse.

Switching off the auxiliary lamp is desirable in order to avoid the risk of even the slightest movement blurring and of incorrect colour reproduction due to the low colour temperature of the incandescent lamp.

Some of the photographs made with the apparatus discussed here, have been reproduced in fig. 2. In spite of the limitations imposed by the printing process, these colour reproductions give an impression of the excellent quality of the original photographs, due to the complete absence of movement during exposure and to the large depth of focus. Apart from providing a reliable record of the patient's condition, these high definition photographs have also proved of value in ophthalmic research. Great interest has lately arisen with regard to the flow of blood through the finest blood vessels of the conjunctiva, especially since Ascher's discovery [4]) of

Fig. 5. Arrangement of camera and illuminating unit on a common stand of the type normally used for examinations of this kind. The patient's head is held in a fixed position by the usual ophthalmic chin-and-forehead rest.

[4]) K. W. Ascher, Amer. J. Ophthalm. **25**, 31-38, and 1174-1209, 1942; **27**, 1074-89, 1944; **29**, 1373-87, 1946.

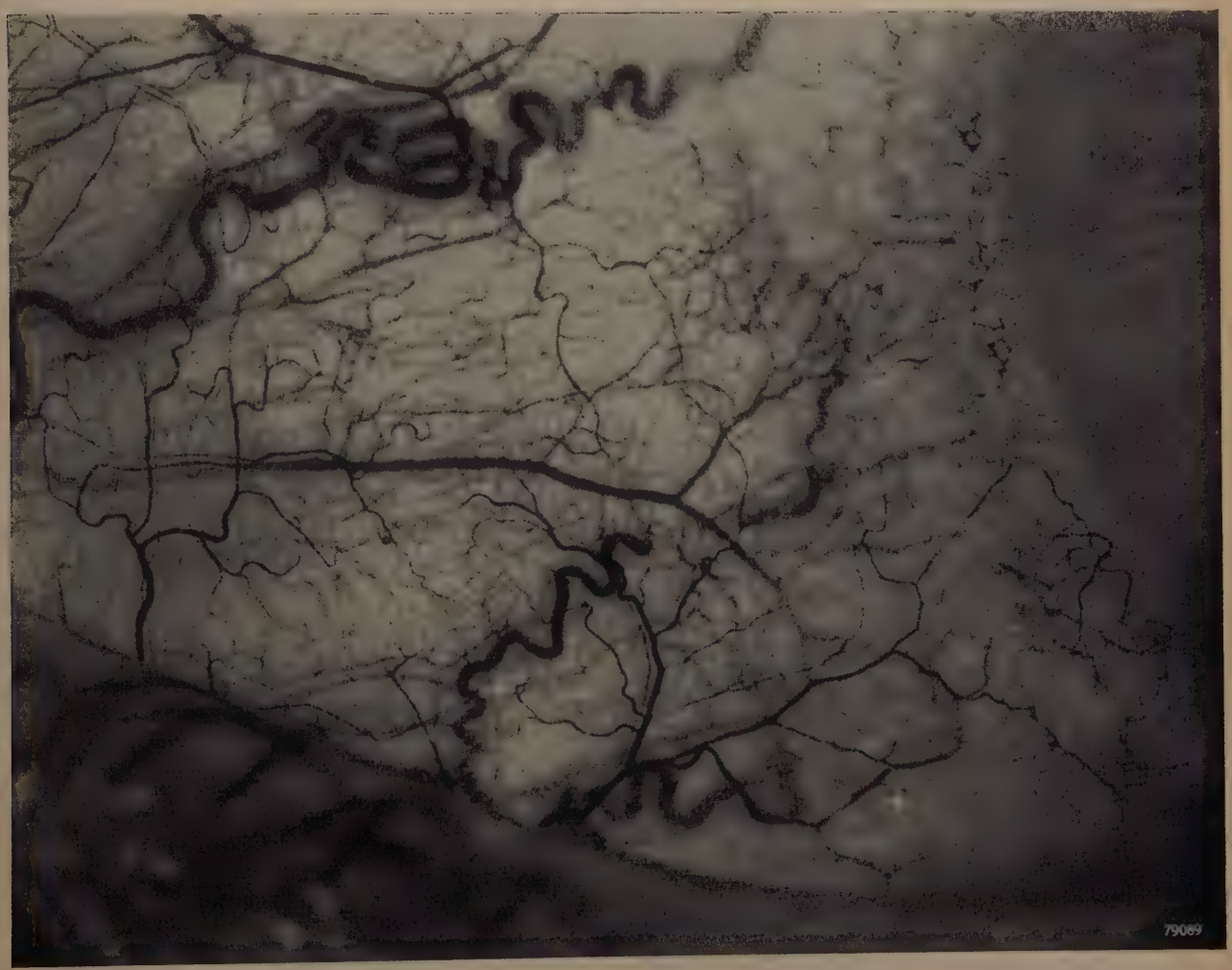

Fig. 6. Part of the sclerotic coat and the conjunctiva of a normal human eye, enlarged about 20×. This photograph was made with the apparatus described in this article. The definition is sufficient to render visible even the fine ramifications of the blood vessels of the conjunctiva. At the right part of the cornea can be seen, and below left, a few eyelashes.

what are termed the "aqueous veins". As a rule these finest capilliaries can be observed only through a corneal microscope. Photography of this delicate network of blood vessels is a most difficult task. *Fig. 6* demonstrates that the definition of the negatives made with the set-up described (i.e. without a microscope) is sufficient to permit enlargements in which these fine blood vessels of the conjunctiva are easily visible.

The flash-tube and the further equipment were developed in cooperation with Drs H. J. J. van Boort of the Laboratory of the Light Group at Philips. Mr G. Lammens of the Amsterdam Ophthalmic Clinic who made the photographs reproduced here, played an important part in the development of the instrument.

Summary. Colour photographs of the externally visible parts of of the eye provide the ophthalmologist with an ideal means of recording his findings. Photographs of this kind require a very large quantity of light, but the hyper-sensitivity of abnormal eyes is a serious obstacle to the use of a continuous illumination of sufficient intensity. An electronic flash-tube, specially designed for use in conjunction with a filament lamp for focussing and sighting (which lights the eye from exactly the same direction) eliminates these difficulties. The lamp operates on a flash energy of only 50 joules. By means of a simple optical system for concentrating the light on the eye under examination, the illumination permits colour photographs of 1.5 × full size to be made with an aperture of *f* 16. Some colour photographs made with the apparatus are reproduced in the article, as well as a 20 × enlargement of a normal eye, in which the extremely fine blood vessels of the conjunctiva are visible, demonstrating the high definition attainable.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk * can be obtained free of charge upon application to the address on the back cover.

2067: H. O. Huisman, A. Smit, S. Vromen and L. G. M. Fischer: Investigations in the Vitamin A-series, II. Allylic rearrangements in the Vitamin A-Series (Rec. Trav. chim. Pays-Bas **71**, 899-919, 1952, No. 8).

By splitting off water from the intermediate hydroxycompounds of the vitamin A-series, allylic rearrangement takes place in the cyclohexene ring. This rearrangement occurs throughout the whole vitamin A-series with those hydroxy-intermediates wherein the hydroxy-group is in an allyl position with regard to the double bond in the cyclohexene ring. The reason why so many attempts to prepare synthetic vitamin A in reasonable yields, starting with "key" intermediates other than the C_{14} aldehyde lead to failure, is outlined.

2068: J. A. Keverling Buisman and P. Westerhoff: Investigations on sterols, V. Thio-derivatives of provitamine D (Rec. Trav. chim, Pays-Bas **71**, 925-932, 1952, No. 8).

A description is given of the synthesis of the thio-analogues of ergosterol and 7-dehydrocholesterol from these two compounds.

2069: H. D. Moed, M. Asscher, P. J. A. van Draanen and H. Niewind: Synthesis of β-phenylethylamine derivates, II. Condensation of phenols with amino-acetonitriles (Rec. Trav. chim. Pays-Bas **71**, 933-944, 1952, No. 8).

A description is given of the condensation of amino-acetonitriles with phenols according to the method of Houben-Hoesch. The condensations have led to the preparation of a number of compounds of the type:

$$R_1R_2N\text{-}CH_2\text{-}CO\text{-}(C_6H_3R)\text{-}OR_3,$$

in which the R denote alkyl groups. A number o β-amino-acetophenones have been converted into compounds with sympathomimetic activity. An investigation has been made into the conditions and the mechanism of the synthesis, and the influence of substituents in the benzene ring on the reactivity of the phenol component. A discussion is devoted to the electronic interpretation of the synthesis according to Houben and Hoesch.

2070: B. Verbeek and A. H. W. Aten: Radiations from arsenic 70 (Physica **18**, 974-975, 1952, No. 11).

Description of the preparation of As^{70} by bombarding arsenic-free germanium oxide with 26 MeV deuterons. The half-life is found to be 52 ± 1 min. Positrons are emitted with maximum energy of 2.7 MeV. The upper limit of the ratio K-capture/β^+-emission is 0.2. Apart from the annihilation radiation, on the average 2 gamma quanta per positron are emitted with energies between 1 and 2 MeV.

2071: B. H. Schultz: Regenerators with longitudinal heat conduction (Proc. Gen. Discussion on Heat Transfer 1951, pp. 440-443, Inst. Mech. Engrs. London).

For the efficiency η of a non-subdivided regenerator (e.g. in a hot-air engine) in the case of large

heat capacity, the formula

$$\eta = 1-2(1+\Lambda\lambda)/q$$

is derived, in which Λ is the reduced surface and λ is the ratio of heat conductance of the regenerator to the heat capacity of the gas transferred per sec; q is a function of Λ and λ. It is shown that the same formula probably holds in the case of a subdivided regenerator (consisting of a number of slabs with no thermal contact between adjacent parts), provided the reduced heat capacity Γ (heat capacity of the regenerator divided by that of the amount of gas transferred per cycle) is sufficiently large ($\Gamma>3$).

2072: H. P. J. Wijn: A new method of melting ferromagnetic semiconductors: $BaFe_{18}O_{27}$; a new kind of ferromagnetic crystal with high crystal anisotropy (Nature **170**, 707, 1952).

A method is described for preparing single macroscopic crystals of magnetite (Fe_3O_4) and of various ferrites (MeF_2O_4), in which Me is a divalent metal. The material is melted in a nitrogen atmosphere by high frequency heating in a crucible made of Al_2O_3, covered by a disc of rhodium or indium, and allowed to cool in an atmosphere containing oxygen, the oxygen pressure being kept equal to the equilibrium pressure. Single crystals several millimeters in size were obtained. By adding barium carbonate, crystals of hexagonal structure with high crystal anisotropy were obtained, e.g. crystals of $BaFe_{12}O_{19}$ (c = 23.2 Å) and $BaFe_{18}O_{27}$ (c = 32.8) Å.

2073: P. Braun: Crystal structure of $BaFe_{18}O_{27}$ (Nature **170**, 708, 1952).

Details are given of measurements of the crystal structure of hexagonal $BaFe_{18}O_{27}$ (see No. **2072**).

2074: J. Volger: Anomalous specific heat of chromium oxide (Cr_2O_3) at the antiferromagnetic Curie temperature (Nature **170**, 1027, 1952).

The susceptibility χ of Cr_2O_3 was measured as a function of T between 80 and 550 °K. There is a discontinuity in the slope of the curve at about 318 °K (45 °C). The molecular specific heat C_p has a sharp peak at 308 °K (35 °C), which is due to the disappearance of the antiferromagnetic ordering at this temperature.

2075: A. L. Stuyts, G. W. Rathenau and E. W. Gorter: Preferred crystal orientation in ferromagnetic crystals (J. appl. Phys. **23**, 1218, 1952).

The compound $BaFe_{12}O_{19}$ is the main ingredient for a sintered permanent magnet material. With crystals oriented at random one obtains $(BH)_{max}$ = (0.8-1.1)10^6 gauss. oersted or (6.5-8.5)10^4 J/m^3. By orienting the crystals in a magnetic field before sintering, values roughly 3 times as large are obtained (see these abstracts No. **2059**).

2076: P. B. Braun: A superstructure in spinels (Nature **170**, 1123, 1952).

It is found that the compound $LiFe_5O_8$ has approximately a spinel structure, but with slight deviations which cause a superstructure. Below 735 °C four lithium ions are distributed in an ordered way over 16 octahedral interstices (with long range order). Above 755 °C the long range order has completely disappeared. By rapid quenching from 950 °C the disordered phase is obtained at room temperature. $LiAl_5O_8$ shows the same superstructure but the transformation region is at higher temperatures. It is pointed out that γ Fe_2O_3 containing water may approach the formula HFe_5O_8 (by analogy with HAl_5O_8). In the $\alpha\rightarrow\gamma$ transformation of Al_2O_3 and Fe_2O_3, protons may play an important part.

2077: H. de Lange: Experiments on flicker and some caculations on an electrical analogue of the foveal systems (Physica **18**, 935-950, 1953, No. 11).

The reaction of the author's right eye to a 2° foveal flicker field has been investigated and measurements of the critical flicker frequency for various illuminations and various brightness-time functions are tabulated. It is shown that in the graph of the ripple ratio (r = amplitude of first Fourier component/average brightness) of the stimulus against the critical frequency f_c, the average brightness being constant, the points observed with various time functions fit into one smooth curve which is monotonic at low intensities. At high intensities the curve shows a minimum, at which r is less than the limiting brightness discrimination ratio, observed for $f = 0$. If f_c is plotted horizontally, the curves obtained suggest an explanation of the mechanism present in the light sensitive organ and the connected nerve centres, by analogy with an electric network containing a lowpass filter, a feed-back circuit and a non-linear element which transforms the physical stimulus into a number of impulses.

R 200: A. Bril and H. A. Klasens: Intrinsic efficiencies of phosphors under cathode-ray excitation (Philips Res. Rep. **7**, 401-420, 1952, No. 6).

Intrinsic efficiencies of thick phosphor layers and their voltage and temperature dependence were

measured with cathode-ray excitation in a demountable tube. The light outputs of thin layers of phosphors coated on glass were also determined. The light output on the glass side goes through a maximum with increasing layer thickness. For sulphide phosphors e.g., the maximum output on the glass side was about 30 percent of that on the phosphor side for a thick layer. Further losses of light occur in practice due to fabrication difficulties and current saturation, so that only 25 percent of the energy of the electron beam is radiated from the sulphide screen of a cathode-ray tube. For an ideally reflecting metal coating, emission of almost 100 percent can be obtained theoretically. In practice (aluminium layer) the maximum gain is a factor 2 or at most 2.2, due to imperfect reflections. From the measurements the scattering and absorption coefficients were determined for sulphide and silicate screens, using the formulae of Hamaker.

R 201: A. Bril and H. A. Klasens: New phosphors for flying-spot cathode-ray tubes (Philips Res. Rep. 7, 421-431, 1952, No. 6).

The decay rates of a large number of phosphors under cathode-ray excitation have been determined. Cerium-activated phosphors are the best for flying-spot cathode-ray tubes used for black-and-white television. Of these phosphors $2CaO.Al_2O_3.SiO_2$-Ce was selected as the best phosphor in combination with glasses not blackened by soft X-rays or cathode ray bombardment. Bismuth-activated phosphors are suitable as a red component in flying-spot cathode-ray tubes for colour television. A suitable phosphor for u-v flying-spot microscopy is ZrP_2O_7.

R 202: R. Vermeulen: Dimensional analysis, units and rationalization (Philips Res. Rep. 7, 432-441, 1952, No. 6).

Undiscriminating manipulation of dimensional formulae can lead to contradictions, e.g. that 1 sec = 3.10^{10} cm or that 1 oersted = 1000 A/m. These are eliminated by defining the multiplication of physical quantities, strangely enough never done before, and by preventing the mixing up of multiplications whose physical interpretations are essentially different. The same measures solve difficulties connected with the introduction of the rationalized Giorgi-system.

R 203: F. de Jager: Deltamodulation, a method of P.C.M. transmission using the 1-unit code (Philips Res. Rep. 7, 442-466, 1952, No. 6).

It is known that in a communication system the influence of interferences in the transmission path can be reduced considerably by coding the information signal first and transmitting then a corresponding pulse pattern of 0 and 1 pulses. In well-known systems of pulse-code modulation the n-digit binary code is used. In deltamodulation, however, a "code" comprising only 1 digit is used. Here the reproduced signal is obtained by applying the series of quantized pulses to a linear network. This system enables us to obtain a simplification of both coding and decoding devices. The conversion of the information signal into a quantized pulse pattern is achieved by using a negative-feedback circuit in which the voltage applied to the feedback network is quantized both in amplitude and in time. The network in the feedback loop should be related to the mean spectrum of the information signals. For speech an integrating network may be used as such. It is found, however, that the frequency characteristic of the feedback network for frequencies lying between the highest speech-frequency and the pulse frequency has its influence on the amount of quantizing noise in the reproduced signal. If a combination of single and double integration in this frequency region is used, the ratio between the r.m.s. values of signal and quantizing noise is proportional to the 5/2 power of the pulse frequency.

R 204: A. van Weel: Measurement of group-delay time in networks (Philips Res. Rep. 7, 467-473, 1952, No. 6).

A well-known principle for measuring group-delay time is based on measuring the phase relations of a low-frequency modulation on a high-frequency carrier, before and after passing an unknown network. The article describes a very sensitive phase measuring device where the phase angle to be measured is introduced in an oscillating circuit, thus influencing the frequency of oscillation. Under certain conditions the phase variations are proportional to the resulting frequency variations. Phase variations of 0.01 degree are measured without difficulty, permitting the measurement of group-delay time variations of 10^{-9} sec, using a modulation frequency of 30 kc/s.

R 205: Y. Haven and J. H. van Santen: On pre-exponential factors in formulae for ionic conductivity in solids (Philips Res. Rep. 7, 474-477, 1952, No. 6).

It is pointed out that, in formulae for equilibrium constants and rate constants, if the energy is linearly dependent on temperature, i.e. $E = E_0 - \alpha T$, the pre-exponential factor i.e. coefficient preceding $\exp(-E_0/kT)$, does not contain the factor $\exp(\alpha/k)$.

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